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The new oil? The geopolitics and international governance of hydrogen

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A B S T R A C T

While most hydrogen research focuses on the technical and cost hurdles to a full-scale hydrogen economy, little consideration has been given to the geopolitical drivers and consequences of hydrogen developments. The technologies and infrastructures underpinning a hydrogen economy can take markedly different forms, and the choice over which pathway to take is the object of competition between different stakeholders and countries. Over time, cross-border maritime trade in hydrogen has the potential to fundamentally redraw the geography of global energy trade, create a new class of energy exporters, and reshape geopolitical relations and alliances between countries. International governance and investments to scale up hydrogen value chains could reduce the risk of market fragmentation, carbon lock-in, and intensified geo-economic rivalry.

1. Introduction

The idea of hydrogen as a clean energy solution has had several false starts, but this time may be different. Major declines in the cost of renewable electricity, coupled with expected cost reductions for electrolysers, have strengthened the business case for green hydrogen. As a CO_2-free energy carrier, hydrogen could help decarbonize hard-to-abate sectors in addition to offering storage and long-distance transportation options for renewable power.

These drivers have given hydrogen new political and business momentum. Australia, France, Germany, Japan, Korea, and Norway have recently issued national hydrogen strategies. Hydrogen is being discussed at the G20, the IEA, IRENA, and other forums. Japan received a first cargo of liquid hydrogen from Brunei in early 2020 and another shipping route from Australia is set to open within a few months. It is increasingly plausible that hydrogen will become an internationally traded commodity. The arrival of the first cargo of hydrogen to Japan could potentially come to be seen as significant a moment as the first delivery of LNG by the Methane Pioneer from the US to the UK in the late 1950s [1]. At the same time, the slow and incomplete globalization of natural gas markets offers important lessons for those betting on a fast expansion of hydrogen trade.

For a global clean hydrogen market to develop, several obstacles need to be overcome. Costs have to come further down, infrastructure must be expanded, and hydrogen needs to be produced from cleaner sources—either renewable electricity or fossil fuels equipped with carbon capture, utilization or storage technologies (CCUS). At present, more than 99% of all hydrogen is still made from (unabated) fossil fuels, leaving a substantial CO_2 footprint [2].

The road towards a global hydrogen market is not just a function of technical and economic factors, however. The possible emergence of a hydrogen economy will also be shaped by, and in turn give shape to, geopolitical dynamics that have hitherto been overlooked. Hydrogen is a blind spot in the emerging literature on the geopolitics of the energy transformation, which has focused mostly on the implications of electrification of end-use sectors through increased deployment of solar and wind power [3,4]. The geopolitical angle is just one of a broader set of social science research questions that the hydrogen transition is opening up [5].

The technologies and infrastructures underpinning a hydrogen economy can take markedly different forms, depending on hydrogen's source, handling, shipping, and end-uses. In political economy terms, each alternative value chain creates its own set of winners and losers [6]. The choice of particular paths to scale up the production will therefore not just be a function of costs and technical efficiency. Struggles and conflicts between different stakeholders in the value chain will shape the creation of a global hydrogen market and affect the pace of the energy transition.

The stakes in this geopolitical game are high. By 2050, hydrogen could meet up to 24% of the world's energy needs, and annual sales of

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hydrogen could be worth USD 700 billion, with billions more spent on end use equipment [7]. Left to its own devices, however, the build-up of a hydrogen economy may result in market fragmentation, carbon lock-in, and intense geo-economic rivalry.

Enhanced international collaboration could help avert these risks and create a liquid and well-functioning global market in hydrogen. International frameworks to harmonize certification and regulations, de-risk investments, support R&D, and provide a roadmap for the 2030 and 2050 roles of hydrogen in the energy transition would all be beneficial and give hydrogen a flying start compared to natural gas/LNG.

2. Hydrogen and the energy transition: State of play

2.1. Technical opportunities and challenges

Hydrogen has long been touted as an important piece of the clean energy puzzle. It is the lightest and most abundant element in the universe, but hydrogen on Earth only rarely exists in its pure form. It is almost always chemically combined with other elements, most notably as water molecules (H2O). Once you free the element from its compound, hydrogen can be converted into electricity through fuel cells, it can be combusted to produce heat or power, or it can be used as a feedstock. When burned in an engine or when combined with oxygen in a fuel cell, hydrogen produces heat or electricity with only water vapor as a by-product, and no other pollutants or emissions.

Hydrogen can be employed across a wide range of applications, across virtually all sectors, from transport to industry to buildings. The IEA sees significant opportunity for hydrogen-based fuels in high-temperature heat production and industries, space heating, powering high-mileage vehicles as well as planes and ships, and seasonal storage for the grid [2].

It is important to note that hydrogen is not an energy source but an energy *carrier*. Just like electricity, it needs to be produced using other sources of energy. Today, hydrogen is mainly produced from natural gas ("grey" hydrogen) and coal ("black" hydrogen). Only a negligible part of current production is from fossil fuels equipped with carbon capture technologies ("blue" hydrogen) or from electrolysis powered by renewables ("green" hydrogen).[1] Converting renewable electricity via hydrogen into other energy carriers – gases, liquids, and heat – and chemical feedstocks is a process known as "Power-to-X" (PtX or P2X). Each of the "downstream derivates" of hydrogen (e.g., synthetic methane, synthetic diesel, methanol, ammonia) comes with its own value-chains. By enabling these conversions, hydrogen has the potential to connect different parts of the energy system, also known as "sector coupling".

Several technical and economic limitations have held back hydrogen, including its explosiveness, low energy density per volume, ability to cause embrittlement in metals and, accordingly, costly infrastructure for production, storage, and distribution. As a consequence, past waves of enthusiasm have not translated into sustained investments or policy support. Between 2008 and 2018, worldwide government spending on hydrogen declined by about 35% [2].

Without some form of "climate neutral molecules" (biogas, hydrogen, synthetic fuels, etc.), however, it will be very hard to achieve deep decarbonization [8]. For sectors such as long-haul transport, chemicals, and metallurgy, it is difficult to curb emissions through electrification alone [9,10]. Efficiency, new materials, the circular economy, and behavioural changes could help to lower overall energy demand in those hard-to-abate sectors. For instance, substituting short-distance air travel with high-speed rail could dent overall demand for jet fuel. Yet, modelling shows the need for some form of green gases or fuels to successfully transition to a zero-carbon energy system [11,12]. Hydrogen and derived fuels such as methanol, ethanol, and ammonia may thus be the "missing link" in the energy transition [13]. Moreover, the rapid expansion of cheap renewable power can simultaneously bring down hydrogen's cost and carbon emissions.

2.2. Dilemmas and trade-offs in scaling up hydrogen value chains

Creating a global clean hydrogen market will require the creation of entire new value chains (see Table 1). The choice over which pathway to take is the object of fierce struggles and conflicts between different stakeholders, including governments that import and export energy, renewable electricity suppliers, industrial gas producers, electric utilities, automakers, oil and gas companies, shipping companies, and cities with major ports.

Table 1
Alternative hydrogen value chain pathways.

	Key pathways
What to produce it from?	**Blue or green hydrogen?**
Where to produce it?	**Home-grown or imported?**
How to handle it?	**Pure hydrogen or derivates?**
What to use it for?	**Selected applications or hydrogen society?**
Where to consume it?	**Exports or industrialization?**

Some of the paths in Table 1 involve a choice between different *technologies* when it comes to hydrogen production, handling and its applications. These technological choices may pit several industrial players against one another, for instance electric car makers versus fuel cell manufacturers. Other paths involve primarily a choice between different *locations* of production and consumption. Since these geographical dimensions come with a geopolitical twist, we explore them in the next section. Here, we discuss the dilemmas with regard to the three major technological choices to be made in scaling up a hydrogen market: production, handling, and applications.

First, in terms of production, today's hydrogen value chains are dominated by fossil fuels. In a decarbonizing world, the key contenders for future hydrogen production are blue and green hydrogen. While each pathway produces the exact same chemical product (H2), they come with a very different constellation in terms of energy infrastructure and industry. Blue hydrogen supports natural gas extraction, transport, and processing and the CCUS industry. Green hydrogen requires cheap electrolysers and could facilitate new investments in renewables by cutting curtailment, addressing negative pricing, and reducing the need to build costly new power transmission capacity (particularly for offshore wind).

The choice of which path to take is fraught with dilemmas. Developing a full-fledged clean hydrogen infrastructure is unlikely to happen without blue hydrogen, given the current scale and cost advantage of hydrogen production from fossil fuels. In many countries, using grid electricity to produce hydrogen would result in more emissions than hydrogen produced from steam methane reformation of natural gas without CCUS (i.e. "gray" hydrogen) [13]. Yet, production of blue hydrogen is not carbon–neutral (since it is impossible to capture all of the CO2 emissions when producing blue hydrogen or eliminate all risks of upstream methane leakages) and can lock in carbon-intensive trajectories and infrastructure (since it requires continued extraction of natural gas). Moreover, blue hydrogen relies on carbon capture technologies which are currently being deployed only at a snail's pace, and often combined with enhanced oil recovery, a process that eventually creates more CO2 emissions.

Second, in terms of handling, hydrogen can be handled in pure form (H2) or it can be converted into other molecules such as synthetic methane, methanol, Fischer-Tropsch (FT) liquid hydrocarbons (e.g., diesel, gasoline, kerosene and lubricants), or ammonia. Each option

[1] There are other methods to produce hydrogen, which come with their own economic and geopolitical challenges, including pyrolysis to produce "turquoise hydrogen" and nuclear hydrogen production ("purple hydrogen").

comes with particular advantages and downsides. Pure hydrogen can only be mixed to a certain extent in the existing gas distribution grid and requires retrofitting of boilers, ovens, furnaces and meters at the consumer's end. These retrofits are not required for synthetic methane, which can be directly injected in the grid. Synthetic diesel can be shipped in product tankers and unloaded at ordinary ports. Methanol and ammonia can be transported by liquid bulk chemical tankers. Synthetic methane, methanol and FT products require a CO2 source. Ammonia, on the other hand, is a carbon-free compound (NH3) but its storage and transportation may pose safety problems as it is highly toxic.

Third, in terms of applications, until now, hydrogen has primarily been used in industry as a chemical feedstock, notably for oil refining and ammonia production.[3] In the future, hydrogen could potentially also function as a versatile energy carrier that could be fed into the gas network, used in fuel cell vehicles, converted to other synthetic fuels, or converted into electricity for the grid. Japan aspires to become the world's first "hydrogen-based society," and envisages a broad range of applications for hydrogen. For instance, battery electric vehicles (BEVs) have an overall well-to-wheel efficiency of ~70-90%, while hydrogen cars only reach ~25-35%. The conversion efficiency of battery electric vehicles (BEVs), compared to only 25–40% for internal combustion engines [14]. There is a risk that hydrogen value chains will be supported at the expense of alternative value chains that are more efficient. In addition, the risk of lock-in is also present here. Hydrogen blending mandates for natural gas pipelines, for instance, could help to lower emissions of gas-based heating and cooking in buildings, but do not lead to zero emissions in and of themselves. They could also slow down the penetration of electric furnaces and heat pumps or conversion into hydrogen dedicated pipelines.

3. Geopolitical aspects of hydrogen trade

The expansion of hydrogen value chains creates difficult trade-offs and dilemmas. Investment in hydrogen infrastructure is needed to bring down overall costs, but it is also risky in the absence of assured supply and demand. Those countries, companies and cities that have betted on the "wrong" pathway, may incur significant losses. Conversely, those actors that are able to gain technological leadership stand to gain significantly. Companies and countries also need to confront another set of choices, related not so much to technology but rather to the geography of hydrogen production and use: industrialized countries need to weigh the option of large-scale imports against the costs and benefits of domestically-produced hydrogen, whereas countries with abundant resources to produce cheap hydrogen can either export hydrogen in large quantities or use it to attract "downstream" industries like iron and steel.

Overall, this leads us to consider three geopolitical implications of hydrogen: the creation of new dependencies between states if the path of large-scale imports is chosen; a change in the interest and actor constellations of the energy transition if hydrogen throws a lifeline to fossil fuel producers and incumbents; and a possible intensification of technological and geo-economic rivalry between countries.

3.1. New dependencies between states

Today, hydrogen is still a very localized industry. Some 85% of hydrogen is produced and consumed on-site, mostly at refineries.[3] To scale up production, industrialized countries may set up hydrogen plants at home or import hydrogen from states rich in renewable (or fossil) energy resources. For major economies like the EU or Japan, importing green hydrogen from regions with comparatively cheap, abundant renewables may help to reduce the cost of the energy transition as well as pressures on domestic resources (space on sea and land) linked to large-scale deployment of renewables. However, such cross-border maritime trade in hydrogen could produce new dependencies between states and give rise to new maritime shipping risks.

Hydrogen thus has the potential to reshape the global map of energy trade and create a new class of exporters (see Fig. 1). Countries such as Japan and South Korea are anticipating large-scale imports of hydrogen. By contrast, the hydrogen strategies of countries like Australia, Chile, and New Zealand focus on the potential for exports. New trade links may thus emerge and, to the extent that hydrogen displaces fossil fuels, it could potentially reduce the pressure on key maritime chokepoints for oil (e.g., Strait of Hormuz) or pivotal transit countries for natural gas (e.g., Ukraine until recently). At the same time, new shipping lanes may gain importance on the map of global energy trade.

For countries with close geographic proximity, hydrogen may be shipped through pipelines. In Northwestern Europe, for instance, a 900 km hydrogen-pipeline network connects Rotterdam (the Netherlands), Antwerp (Belgium), and Dunkirk (France). Worldwide, there exist already more than 4,500 km of hydrogen pipelines [15]. German gas pipeline operators have recently unveiled plans to build a hydrogen grid of around 5,900 km, which would be by far the world's

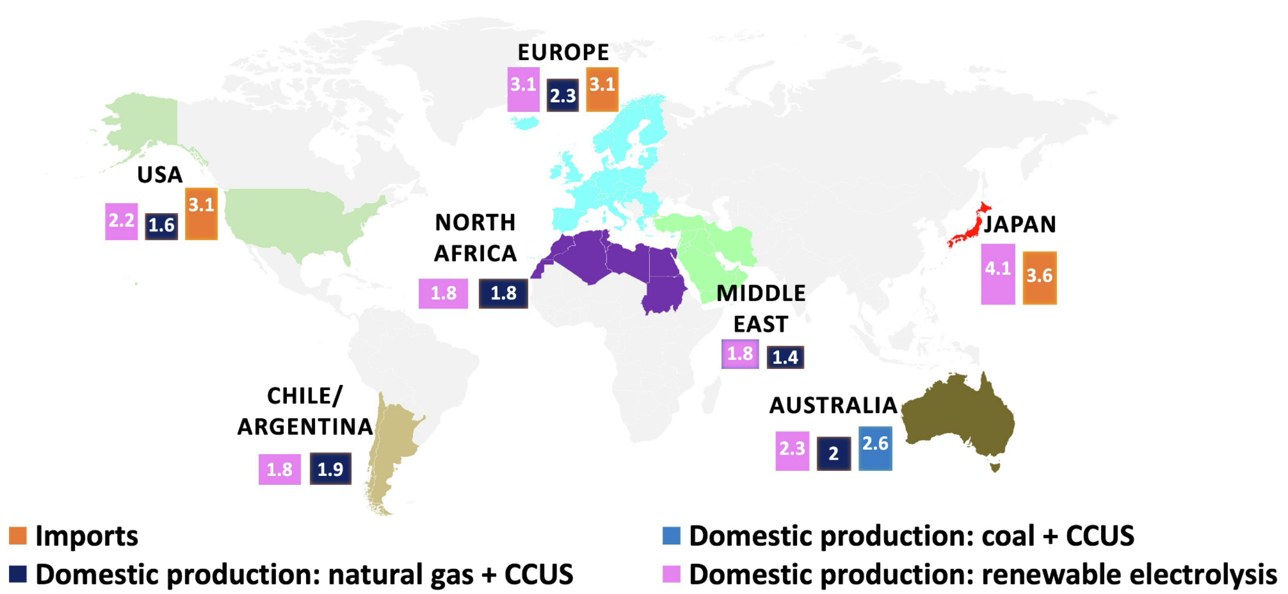

Fig. 1. Costs of different hydrogen types by location, USD per kg of hydrogen [2].

largest. While these regional and local networks could be combined into transregional networks, there is as of yet no experience with long-distance hydrogen pipeline transportation.

Several countries are already engaging in what could be called "hydrogen diplomacy." The Dutch government has even appointed a special "hydrogen envoy." Japan's diplomats and industrial stakeholders are engaging Australia, Brunei, Norway, and Saudi Arabia on hydrogen fuel procurement [16]. Germany has signed a cooperation agreement with Morocco on methanol production from hydrogen, South Korea has its eyes on Norway, the Netherlands is targeting Portugal as a potential supplier of hydrogen, and industrial players in Belgium are looking towards Oman and Chile for large-scale hydrogen imports.

If the current trend toward bilateral partnerships continues, the market could start from a highly fragmented base, mimicking the experience with the initial phases of the LNG market [17]. The first LNG projects were subject to inflexible, bilateral, long-term contracts with oil-indexed prices—and were therefore sometimes referred to as "floating pipelines." Japan spearheaded the development of the LNG market by emerging as the first big buyer. Its commitment to large-scale hydrogen imports could make it, once again, global gas market pioneer, this time in hydrogen.

One of the key differences with trade in crude oil or natural gas is that hydrogen trade will be less asymmetric. It is technically possible to produce hydrogen almost everywhere in the world. The fact that many countries could become *prosumers* (both producers and consumer of hydrogen) and that hydrogen can be stored makes it almost impossible for exporters to weaponize hydrogen trade or for importers to be trapped by a small cartel of suppliers. Yet, hydrogen trade will not be as reciprocal as cross-border trade in electricity, where electrons actually travel both ways depending on supply and demand conditions on both sides of the border. Still, international trade in hydrogen will boost the energy security of importers as it will provide a back-up to the electricity system.

3.2. The politics of the energy transition

Instead of focusing narrowly on technologies and costs, governments have to manage the geo-economics of hydrogen. The potential for centralized production and distribution of hydrogen offers opportunities to co-opt segments of the fossil fuel industry into the energy transition *and* throw a lifeline to petrostates. This potential could perhaps be politically leveraged in order to maintain at least the minimum commitment of oil exporters such as Russia and Saudi-Arabia to the Paris Agreement.

For the oil and gas exporting countries in the Middle East and North Africa (MENA) region, hydrogen could be an answer to one of the big challenges they are facing today: how to diversify their economies away from reliance on oil and gas export revenues. These countries have several advantages, including the availability of abundant, low-cost solar (for producing green hydrogen), underground storage options for carbon sequestration (in case the blue hydrogen production route is taken), and a geographic location that is ideal to serve both European and Asian markets. The non-oil economies in the region, including Morocco, could also take advantage of their low-cost renewable energy abundance. Yet, the region's potential might be undermined by limited freshwater availability, which would require additional investment in desalination capacity, which would in turn drive up costs.

Hydrogen could also convert some of the incumbent industries to the cause of the energy transition and, as such, tip the balance in favor of a rapid and deep decarbonization trajectory. The oil and gas sectors have taken a particular interest in hydrogen, which involves the production, transport and distribution of (combustible) fuels, an activity they are most familiar with. Moreover, the existing gas infrastructure can to some extent be repurposed for hydrogen which is why this fuel is championed by the incumbent natural gas actors, particularly the pipeline distribution companies.

3.3. Geo-economic competition

Controlling the value chains of low-carbon energy technologies is vital for economic competitiveness, national security, and energy independence. Early movers in the hydrogen industry might be able to sell their technology to the rest of the world. Technology leadership might be developed around many aspects of the hydrogen value chain, including fuel-cell membranes or precision-engineered storage tanks, pipeline materials or burners. In June 2020, Germany announced that it would spend 9 billion euros to expand hydrogen capacity as part of its post-covid-19 recovery plan and in a bid to make the country a key supplier of the technology worldwide. Concomitantly, German electricity utility RWE and steelmaker Thyssenkrupp launched a partnership to produce green hydrogen and use it for the production of steel.

The race for technology leadership is clear in many countries and sectors. Consider automotive: Japanese car makers Honda and Toyota are betting that fuel cell vehicles will triumph over batteries, especially in terms of range, while Chinese car makers are making big strides in electric vehicles, and German car makers have long focused on making diesel-powered combustion engines more efficient. In many cases, public money is underpinning efforts to deploy hydrogen value chains, making this even more the territory of geo-economic competition. That is why the EU Commission has announced that it will shortly launch an EU Hydrogen Alliance in a recent document on a "new industrial strategy for Europe" [18]. Bloomberg New Energy Finance (BNEF) estimated that electrolyzers were already 83% cheaper to produce in China than in Western countries in 2019 [7], which might stir fears in Europe and North America about China dominating yet another critical energy technology (after obtaining leading positions in rare earths, solar photovoltaic (PV) module manufacturing, EVs, etc.).

The emergence of inter-continental hydrogen value chains will also intensify industrial competition between countries about the siting of energy-intensive industries. Countries with a lot of potential to make hydrogen from indigenous resources (either renewables or fossil fuels) might opt for expanding their value chains into energy-intensive industries such as chemicals and steel, instead of simply exporting hydrogen to industrialized countries. Hydrogen trade could thus add a new dimension to geo-economic rivalry among major powers. Moreover, to the extent that developing countries are seen solely as the providers of raw materials, the hydrogen revolution carries a risk of "green colonialism."

4. Frontrunners and coalitions

The road to an integrated, well-functioning and clean global hydrogen market is thus fraught with uncertainty and risks. It could easily end up like natural gas—largely traded within countries or on fixed, long-term, bilateral contracts between countries. International governance could help scale up investments in hydrogen value chains, while damping market fragmentation, carbon lock-in, and the emergence of new geopolitical risks.

More than 19 frontrunner countries have recently issued hydrogen roadmaps and strategies [19]. These national strategies differ markedly in terms of hydrogen production pathways, applications and geography. What is needed now are international rules on standards and certification that make it possible to identify the carbon content of hydrogen and derivative fuels. If hydrogen is to become carbon–neutral or possibly even contribute to negative CO_2 emissions (by producing hydrogen from biomass and combining it with carbon capture), certification will be key.

In parallel, a concerted vision is needed of the role for hydrogen in the global energy system in 2030, 2040, and 2050 in line with the Paris Agreement. Because of the danger of carbon lock-in and the need to de-risk investments, frank discussion is needed about a gradual phase out of gray hydrogen. Ideally, an internationally agreed framework with a sequential expiration of "color" certificates would pave the way till 2050. To kick-start a hydrogen economy, the "chromatics" may initially have to be neglected. Paradoxically, blue hydrogen currently has a lower carbon footprint than electrolytic hydrogen in most regions—because of their current electricity mixes [20].

The economics of green hydrogen are improving. The cost of alkaline electrolysers already fell 40% from 2015 to 2019 [7]. Electrolysers have a modularity reminiscent of PV modules and may repeat the spectacular cost reductions seen in the solar industry. To help make green hydrogen competitive with natural gas, public support is needed, ranging from targets to R&D and subsidies. In particular, governments will have to put a price on carbon [21]. It is important to keep in mind, however, that even if green hydrogen becomes cheaper than blue hydrogen (possibly with the help of a carbon price), it still needs to compete with petrol, diesel, marine fuel and kerosene for many of its potential applications, especially in transportation [22].

5. Building a hydrogen economy

Building an international hydrogen economy may be critical for meeting the Paris climate goals but would benefit from a concerted effort by multiple actors.

The existing national hydrogen roadmaps offer important stocktakes by *national policymakers*, but they would be even more useful if they were strung together into regional and even global roadmaps. National energy security and industry interests need to be balanced against the *common interest in mitigating climate change and ensuring geopolitical stability*. *National governments* are also key to guarantee a stable and long-term policy framework and a stimulating business climate. As a consequence of recovery programs in response to the Covid-19 pandemic, states might become actors in the hydrogen value themselves.

Pulling the strings together is not a foregone, as a dedicated forum does not exist. The experience of the natural gas sector indicates that coordination—not to mention the creation of an international organization—can be difficult [23]. However, hydrogen has the advantage over natural gas of a possible link to decarbonization and the force of the climate agenda. There are several international organizations which can contribute to discussions on hydrogen pathways and certification. The *International Renewable Energy Agency* brings expertise on renewables and green hydrogen, the *International Energy Agency* has worked on hydrogen from an energy security point-of-view, while the *International Atomic Energy Agency* is providing insights into nuclear hydrogen production. The *International Energy Forum* provides a platform for dialogue between energy sellers and buyers and could expand into the hydrogen sector. Getting these organizations to work together would require skillful steering and leadership, which could be done by the *G7 and G20* as potential governance clubs. There is ample need for both, consumer–consumer cooperation to create converging regulatory frameworks and certificates. Moreover, a producer–consumer dialogue can be conducive to define phasing-out fossil-fuels and phasing in hydrogen pathways.

Corporations and investors will take another hard look at the business case for hydrogen and weigh the risks of yet another false start against those of missing out on a major opportunity that could finally be coming to fruition. Yet, the goal of carbon-neutrality by mid-century has become part of their bylaws in many cases.

Researchers and policymakers need to pay more attention to the international politics of hydrogen. Cross-border maritime trade in hydrogen has the potential to redraw the geography of energy trade, create a new class of energy exporters, and reshape geopolitical relations and alliances between countries.

If national authorities, international organizations, researchers, and companies can pull together along these lines, it may indeed turn out that the time is ripe for the hydrogen economy—and that its geopolitical consequences can be managed.

Conflict of interest

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